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AGRICULTURAL EXPERIMENT STATION,
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LINING OF DITCHES AND RESERVOIRS
TO PREVENT SEEPAGE LOSSES.

BY ELWOOD MEAD AND B. A. ETCHEVERRY.

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LININGS OF DITCHES AND RESERVOIRS TO PREVENT SEEPAGE LOSSES.

INTRODUCTION.

The water which sinks into the soil from ditches and reservoirs is one of the chief sources of waste in irrigation. In gravelly soils, or where ditches cross gypsum strata, the losses sometimes amount to more than half the total flow. Measurements on a large number of ditches, made by the Office of Experiment Stations, show an average loss on main canals of about one per cent for each mile that water is carried; on laterals the loss amounted to between 11 and 12 per cent per mile; while on some California canals the loss in a single mile was 64 per cent.* The water which escapes is often worse than wasted. It collects in the lower lands, fills the soil, drowns the roots of trees and plants, brings alkali to the surface, and is a prolific breeding place for mosquitoes.

On large and costly aqueducts or important storage works, linings of cement, concrete, or asphaltum may be employed without the expense being prohibitive. But the great bulk of these losses occur on lateral ditches and small storage basins where some simpler and cheaper method of making the surface impervious to water must be found; and if ditches can be lined with this substitute by methods which can be carried out by farmers or unskilled laborers, a great improvement in irrigation practice and a marked increase in the duty of water will be brought about.

Muddy water soon silts up muddy ditches, but where the water is clear seepage losses are likely to be permanent and some sort of lining to stop this becomes an important matter. As water drawn from wells or reservoirs is always clear, methods of preventing seepage are live problems where water is pumped or stored. Measurements made in 1906 on a storage reservoir having a surface of 10,000 square feet showed a seepage loss of 1,000 cubic feet per day. The reservoir is filled by a windmill and this loss was 10 per cent of the average quantity pumped each day—a loss too heavy to be borne. The problem of this reservoir owner is the problem of hundreds of irrigators. Unless this

* Bulletin 158, U. S. Office of Experiment Stations, pp. 36-37.

leak in the reservoir can be stopped, the attempt to irrigate by pumping will be a failure; but the owner can not afford the expense needed to line the reservoir with concrete or asphalt, because the value of the water stored will not justify this expense. Puddling has been tried, but there is not enough clay in the soil, and no other material or process has been tried sufficiently to make it safe for him to adopt it. His problem is, therefore, to find some cheap and valuable material or some process which he can utilize at small cost which will make the reservoir hold water. There are an unusual number of raw materials found in California which promise well, and the richness of the mineral wealth of the arid region leaves little doubt that other things besides cement and clay will come into use to prevent the leakage of reservoirs and ditches. The purpose of this investigation is to determine what is the relative merit and expense of both those expedients which have been tried and those which seem worthy of a trial.

The investigation was undertaken by the California Experiment Station, which was assisted at the outset by the U. S. Office of Experiment Stations, which furnished part of the money expended. This bulletin gives the results of the first year's work and is only a progress report. The investigation will be continued on a more extended scale during 1907. The investigations and experiments of 1906 were carried out by Prof. B. A. Etcheverry, of the University of California, whose report follows.

ELWOOD MEAD.

INVESTIGATIONS AND EXPERIMENTS.

By B. A. ETCHEVERRY.

Examination of Lined Ditches in Southern California.—About 1880 all surface waters in southern California were being diverted and used. The heavy profits derived from irrigation and the rapidly increasing price of orange land since then caused a great demand for additional water. The development of the country depended on water, which was, and is even more so at present, the most important question for that locality. All available water supply must be developed and all waste prevented. This meant the rapid development of underground waters by wells and tunnels and the storage of flood waters, and explains the large number of wells yielding probably a good deal more water than the flow of surface water in midsummer.

It was here naturally that the loss of water due to seepage was first felt. Every drop of water saved meant increased prosperity. The value of water increased rapidly after 1880. Water valued at \$30 per miner's inch in 1880 had a value of \$300 January, 1883, and \$720 in 1888. This naturally meant better use of water and a higher duty of water. The duty of water increased to one miner's inch for four or five acres, and has still increased until at present this duty for some of the best citrus lands is one miner's inch for ten acres.

Most of the improvements for economy of water and for the decreased loss in transportation were started after 1880.

Canals were first paved to prevent seepage and erosion; and to permit the use of an economical section. This paving was then improved upon by paving and cementing. Plastering with cement mortar and the use of concrete for lining came into use soon after.

At about the same time the use of steel or cement pipes was introduced. They have since become much in favor in southern California, when the volume of water to distribute is not large, and have to a great extent replaced the smaller open ditch.

While for these parts of southern California there is no doubt but what the use of cement in some form will always be the most generally used material for canal lining, it is expensive and its use is only justifiable where the value of water is very high, or where excessive seepage must be stopped.

For districts where water is plentiful the seepage loss may not be of so much consideration, or at least not so great but that a concrete lining would be prohibitive. The canals or even the laterals of these districts carry several times more water than the largest canals of southern California. The lining, if concrete were used, would have to be stronger and the cost large.

Other considerations besides seepage must, however, be studied before one can decide whether it will be beneficial to line the water channels, and other linings should also be investigated.

A good lining should fulfill the following requirements: (1) It should stop seepage; (2) It should prevent gophers and squirrels from burrowing through the banks; (3) It should prevent vegetation; (4) It should prevent scouring; (5) It should not be easily damaged by the tramping of cattle and by the action of the weather.

No doubt concrete will answer for all these requirements, but cheaper linings in many cases will be more economical. It was mainly to inquire into this that these investigations were undertaken, in May, June, July, and August, 1906.

These investigations include first a journey around some of the irrigated districts of California to learn the different types and methods of lining canals in use, their cost and detail of construction.

CANAL LININGS USED IN CALIFORNIA.

Naturally the best types of canal linings are in southern California, very little having been done in other parts of the State.

A study of the various types shows that they can be classified as follows:

(a) River boulders set in lime mortar and pointed with cement mortar.

(b) River boulders or cobbles placed behind a wooden form and cemented together with cement mortar rammed between the cobbles.

(c) Cement concrete from 3 to 6 inches thick.

(d) Cement mortar plaster $\frac{1}{2}$ to 1 inch thick.

(e) Heavy road-oil.

(f) Clay puddle.

RIVER BOULDERS SET IN LIME MORTAR AND POINTED WITH CEMENT MORTAR.

This method has been extensively used in the San Bernardino Valley. Good examples of this type are seen in Redlands, Crafton, Highlands, and San Bernardino. This type of lining was probably introduced in 1882 to 1883, when the Ontario Colony Enterprise, receiving its water from the San Antonio Cañon, paved its canal, 5 feet wide at the

bottom, 6 feet wide at the top, and $2\frac{1}{2}$ feet deep, with rocks laid in hydraulic lime water and plastered over with cement mortar. This lining was 8 inches thick and cost about 60 cents per lineal foot, or about 6 cents per square foot, which is very much cheaper than the average cost per square foot of this type of work since then. This low cost is probably accounted for by the cheap Chinese labor used at that time, the rate being \$1.25 per day; also the small cost of the lime, \$1 a barrel, and the rock not having to be handled at great distance.

The cement plaster was mixed in the proportion of one part of cement to three parts of sand with lime water. The bottom was finished with a



FIG. 1. New Bear Valley Water Company's Canal; lined with cobbles set in lime mortar and pointed with cement.

thin coating of cement and sand in equal quantities. The lime mortar was one part of lime to five parts of sand.

This type of lining, while largely used since then, is now employed mainly where repairs are necessary. Accurate data as to cost and details of construction are difficult to obtain. A great deal of this work has been replaced with pipes. The new Bear Valley Water Company and also the Crafton Water Company have good examples of this construction. The ditch known as the Highlands Ditch, and the Old Redlands Ditch, known as the South Fork Ditch, both diverting water from the Santa Ana River, are paved and cemented. While parts of these ditches were first paved with cobbles or rocks without the use of lime or cement mortar, or paved with cobbles or rock faced with cement mortar without the use of lime mortar, the more recent type of construction consists mostly of cobbles laid in lime mortar and pointed or faced with cement

mortar. The method of construction used by the Bear Valley Water Company is as follows:

The ditch is excavated to a definite cross-section, this cross-section being of such size that after receiving a lining of about 1 foot in thickness it will be the required finished cross-section. After the excavation, mold frames with boards are used to guide the lining work; between the mold boards and the sides is a space of 1 foot which is the thickness of the lining. Into this space a layer of cobbles about 1 foot in thickness is built, with the interstices filled with small stones; a grout formed of one part of lime to seven parts of clean, sharp sand is then poured in and tamped in order to fill all voids. The lining of the sides is

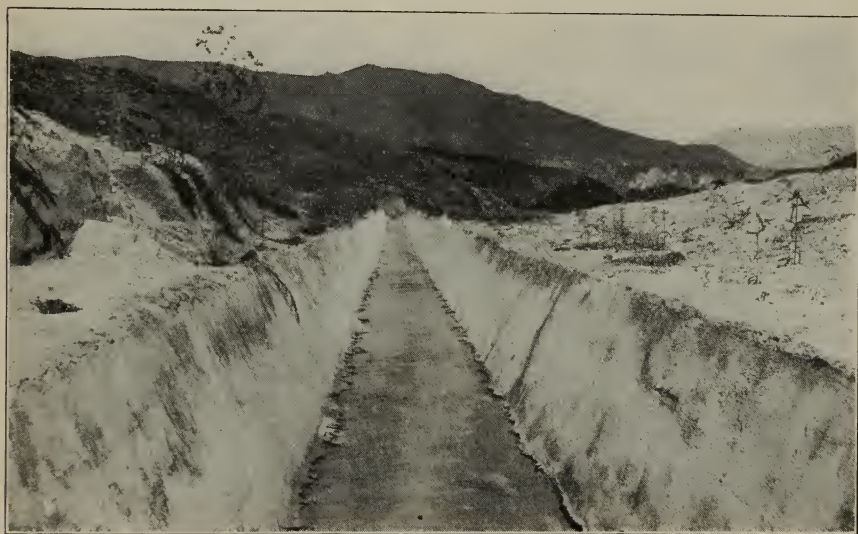


FIG. 2. Hemet Land and Water Company's Canal; lined with cobbles set in cement mortar.

built up in this manner in consecutive layers 1 foot at a time. The bottom is usually paved before the sides, the mold frame resting on the bottom. The lining is generally allowed a few days to harden, then the mold boards are removed and the cement plaster put on. This plaster is a mixture of one part cement to three parts of clean sand and is applied about $\frac{1}{2}$ inch thick, giving a smooth surface.

The size of the ditch thus lined was $2\frac{1}{2}$ to 3 feet wide at the bottom, about 4 feet deep, and side slopes of about 1 on 4. (Fig. 1.) The approximate cost was 15 cents a cubic foot. The price of labor and materials was as follows: Cement, \$3.75 a barrel; lime, \$1.30 a barrel; ordinary labor, \$2 per nine-hour day; masons, \$3.50 to \$4 per eight-hour day.

The method used by the Crafton Water Company was very similar.

The ditch was excavated with scrapers and shovels. No form was used for lining; the sides and bottom were put in by line, the cobbles being placed to line and grade in lime mortar, the interstices between cobbles being filled and chinked. The surface was evened off by forcing in cement mortar with a trowel, and a coating of this cement mortar about $\frac{1}{2}$ inch thick covered the sides and bottom. The rock lining was about 1 foot in thickness. This work was done in 1893, thirteen years ago, and was limited to the intake canal (one mile long) of the Crafton Water Company. According to one of the former directors of the

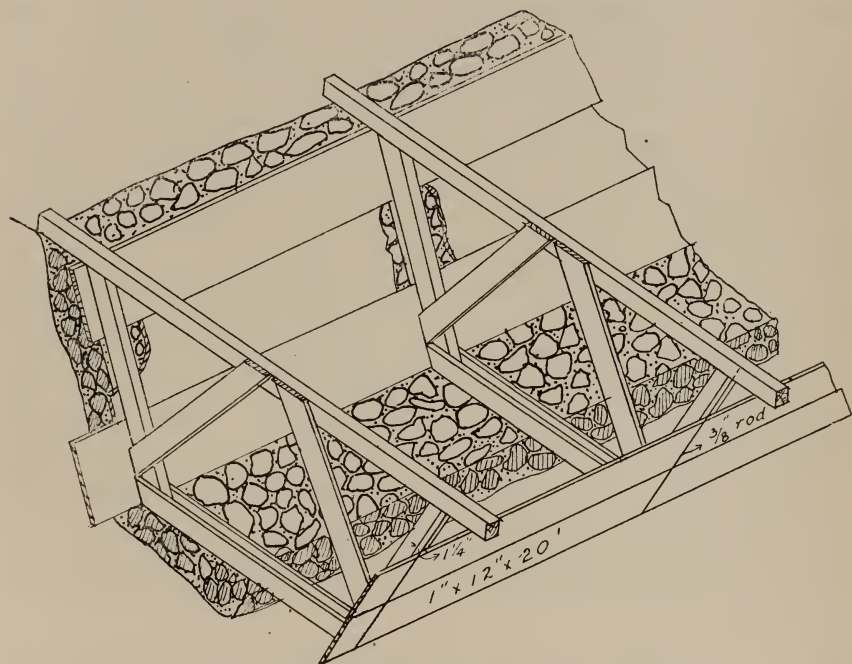


FIG. 3. Method of lining the Hemet Land and Water Company's Canal.

company no repairs have been made during these thirteen years. The work is still in good condition. The average cost of this class of lining would probably be about 13 cents per square foot. While substantial and satisfactory, a stronger and not much more costly is the next class described.

RIVER BOULDERS OR COBBLES SET IN CEMENT MORTAR.

A good example of this work is a section $3\frac{1}{2}$ miles long on the main canal of the Hemet Land and Water Company. One mile of this canal has a bottom width of 4 feet, a depth of 3 feet, and a top width of 7 feet. (Fig. 2.) The remaining $2\frac{1}{2}$ miles have a bottom width of 3 feet, a top width of 6 feet, and a depth of 3 feet.

The canal was excavated with scoop scrapers and shovels. No form was used in the excavation, the cross-section being finished, ready for the lining, by the shovelers. After the excavation, the banks were well moistened by letting the water into the excavated canal and holding it by earth dams. When the banks were thoroughly wet the water was drained out and the lining put on.

The lining consists of cobbles, most of them not less than 6 inches in dimension, placed in the cement mortar. The bottom was constructed first, the cobbles being laid in the bed of cement mortar and the space between cobbles well filled in and finished smooth and to grade. This cement mortar for the bottom consisted of one part of cement to four parts of clean river sand. A little lime was added to this mortar.

Closely following the lining of the bottom came the lining of the sides. (Fig. 3.) For this, mold frames and mold boards were used. The frames were placed 5 feet apart and so constructed that the mold boards were held in place against the frames by a $\frac{3}{8}$ -inch iron rod. The mold boards could be put in one at a time, and one section 20 feet in length was finished at one time.

The mold frames having been put in position and the lowest mold board placed on each side, a layer of cement mortar was spread on the bottom; in this mortar were embedded cobbles, another layer of mortar put on top of these cobbles, then successive layers of cobbles and mortar until the side lining was completed for the section. Mold boards were put on as the lining was built up. The mixture was also tamped during construction to assure the filling of all spaces between cobbles. The ingredients used for the mortar in this lining of the sides were one part of cement to six parts of river sand. After the forms were removed the sides and bottoms were finished with a very thin wash of neat cement.

The cost of cement was \$3 a barrel, delivered on the grounds. The cobbles were close at hand. The cost of labor was \$1.75 for common labor per nine-hour day and \$3.50 for masons per nine-hour day. The total contract price for excavating and lining the ditch was \$25,000, or an approximate cost of 13 cents per square foot, for the lining.

CEMENT CONCRETE.

The best examples of this kind of construction are seen south of Los Angeles near Orange, Santa Ana, and Anaheim. In this vicinity two irrigation companies, both diverting water from the Santa Ana River, afford good illustrations of this efficient lining. These two companies are the Anaheim Water Company and the Santa Ana Irrigation Company.

The Anaheim Water Company has lined its main canal and laterals

with a thickness of concrete varying from 4 inches for the larger canal to 2 inches for the smaller laterals. The work of lining has been done very thoroughly and with great care. If the canal is an old earth ditch it is prepared for the lining and carefully finished as described below.

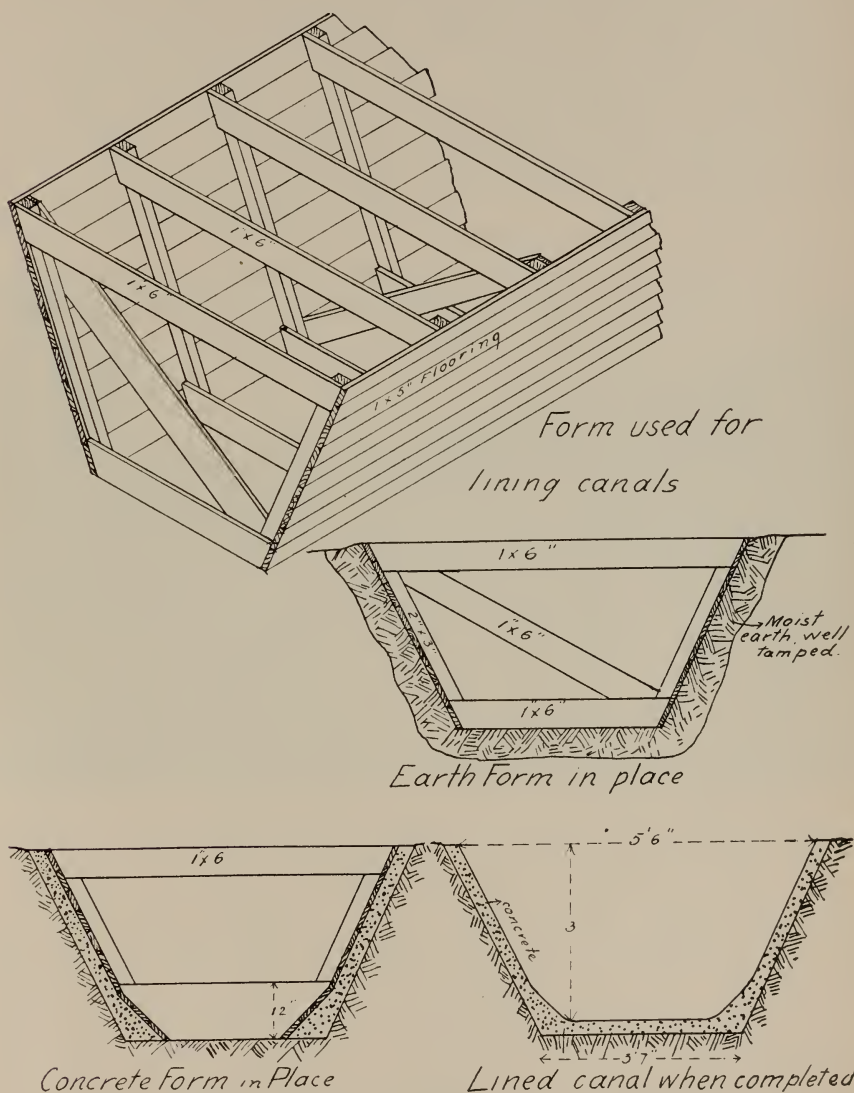


FIG. 4. Method of lining the Anaheim Water Company's Canal.

If the canal is to be constructed and then lined the excavation is made with shovels, or with teams where more economical, the excavation being generally preceded by a thorough irrigation to settle and soften the ground. The excavated cross-section is made larger than the finished cross-section by the thickness of the lining. The bottom of the ditch

is carefully graded and tamped so as to give a solid, smooth surface. A wooden form is placed on the bottom of the excavated ditch. (Fig. 4.) This wooden form is a trapezoidal trough with no bottom, 16 to 20 feet long, depending on the size of the ditch; to make it rigid the frames on which the side mold boards are nailed are placed every 2 feet. The trough is placed in such position that the axis of the ditch coincides with the axis of the form. Moist earth from the excavation is shoveled behind this form and is well tamped in successive layers; at least 6 inches of earth on each side is packed solidly in this manner. The earth form is now removed and before the earth has had time to dry the lining is put on. For the lining another form, smaller than the earth form, is used. For some of the laterals this form was given a peculiar shape (Fig. 4), with the idea of strengthening the lining, and giving the ditch a slightly curved form at the bottom, the corners being rounded. The form is built with the usual side slopes of $\frac{1}{2}$ on 1; the slope is made flatter for the lower 8 inches, where a slope of 1 on 1 is used. The depth of the form is equal to the depth of the lined section plus the thickness of the concrete. The form for larger canals is similar to the earth form. It is placed on the bottom of the finished earth ditch and properly aligned; the concrete, which is mixed rather wet, is now thrown in the space between the form and the earth and well tamped. The side lining having been completed, the form is removed and the bottom lining put on. Wherever possible the concrete is kept wet while setting by allowing water to run in the ditch, and retaining it by earth dams.

The concrete is made of one part of cement to seven parts of coarse gravel of varying size.

The main canal which is lined has a bottom width of 5 feet, a depth of $4\frac{1}{2}$ feet, side slopes of $\frac{1}{2}$ on 1, and the thickness of the lining is 4 inches. The cost per square foot was approximately $10\frac{1}{2}$ cents. The cost of cement was \$2.85 per barrel. The cost of gravel was 60 cents per cubic yard, and the price of labor used in finishing the ditch \$1.75 per day. The price of labor in concreting the ditch was \$2.00, foreman \$3.00 per day. For a smaller canal of $1\frac{1}{2}$ feet width, 3 feet deep, slopes of $\frac{1}{2}$ on 1, the thickness of the lining was 3 inches for the sides and 4 inches for the bottom, and curved or reinforced corners. The cost was 11.4 cents per square foot, including excavation. The cost of labor and material was higher—cement \$3.30 per barrel, gravel \$1 per square yard, and all labor \$2.00 per day. The approximate cost for finishing the sides and bottom and for lining (excluding the main excavation) would be 10 cents per square foot for a 4-inch lining. A corresponding cost for a 3-inch lining (including finishing and lining) would be about 8 cents per square foot.

Some of the smaller laterals are 8 inches at the bottom and 18 inches in depth, side slopes $\frac{1}{2}$ on 1. A lining 2 inches thick costs nearly 6 cents per square foot.

The Santa Ana Valley Company has lined a portion of its main canal above the town of Olive, in Orange County (Fig. 5); the lining is a good example of this kind of work. The canal is $10\frac{1}{2}$ feet wide at the bottom, $41\frac{1}{2}$ feet deep, and 15 feet wide at the top. The lining is $2\frac{1}{2}$ to 3 inches in thickness and was constructed in very much the same manner as the work of the Anaheim Union Water Company. The cost of preparing the sides and bottom for the concrete lining and of lining was 8 cents per square foot.



FIG. 5. Santa Ana Valley Company's Canal; lined with cement concrete.

CEMENT MORTAR.

This method is probably used more extensively in southern California than all the other methods combined. It has proven very efficient and its cost is small. Examples of this class of lining are numerous all through the irrigated districts of southern California. Some of the best types are in the vicinity of Riverside, where the three irrigation companies—the Gage Canal Company, the Riverside Water Company, and the Jurupa Company—have used it extensively. The lining usually consists of a cement mortar plaster, varying from $\frac{1}{2}$ to 1 inch in thickness. Various methods are used in preparing the canal for the lining and in applying the lining.

The Gage Canal Company began making improvements on its main canal in 1886; from 1886 to 1890 this was reconstructed, the total length

being 20 miles. In 1890 the control of the Gage Canal Company passed to the Riverside Trust Company. The conditions prevailing at that time are fully discussed by Mr. Irving, the engineer of the company, in the report of Irrigation Investigations for 1901 (part 2), prepared by the Office of Experiment Stations. The conditions were those usually encountered by other systems where the canals are not lined, viz:

1. Serious breaks in the canal, causing large waste of water and inconvenience to irrigators. Large fills were always in danger of

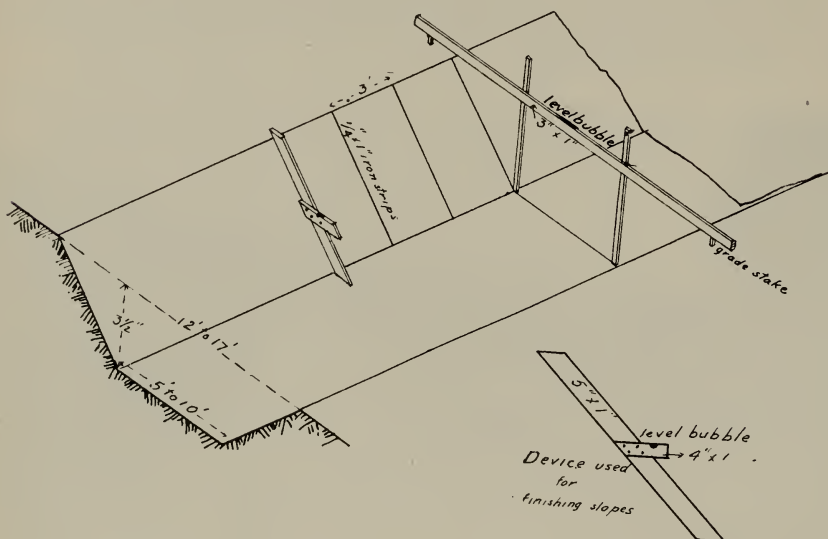


FIG. 6a. Method of lining canals used by Gage Canal Company.

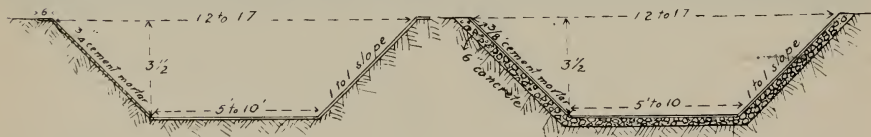


FIG. 6b. Gage Canal in cut and in fill.

breaking, because of settlement of the ground and because of the holes dug in the banks by burrowing animals.

2. Rapid growth of weeds, which decreased the velocity of flow of the water, thus diminishing the carrying capacity.

3. Large losses of water due to seepage.

In 1890 it was decided to remedy these conditions by making an experiment in canal lining by applying a cement mortar plaster on the sides and bottom of the canals. The method used as described by Mr. Irving and supplemented by information given by Mr. Mylne, the present engineer of the company, is as follows:

Method of Cutting and Preparing the Water Channel for the Lining (Fig. 6).—The grade stakes were located on the banks at a given distance from the top of the sloping sides, usually 1 foot. These grade stakes were spaced at intervals of 20 feet. A level rod or cross-section rod of sufficient length to reach from one bank to the other was held at right angles to the ditch, with one end on the grade stake and the corresponding stake set on the other bank. The location of the bottom stakes was obtained by measuring from this rod, by which means they were placed in alignment and to grade every 20 feet. A line was stretched at the bottom between the 20 feet grade stakes, and the bottom was then cut to grade. Strips of iron, 1 inch wide and $\frac{1}{4}$ inch thick, and about equal in length to the length of the sloping sides, were placed on the sides every 3 feet, extending up and down the slopes, the slope given them being the slope of the finished ditch. They were set in position by the use of a specially constructed device as illustrated, which gives the correct slope, the grade line giving the proper position for the lower end of the iron rod.

These iron strips were set every 3 feet along the slopes. A sharp iron straight edge, a little over 3 feet in length, was used to shave off the irregularities between them; or if below the alignment, the depression was filled in and well tamped. Usually there were two gangs of men; the rough finishers came first and removed the larger irregularities, tamping the sides and bottom; then the smooth finishers brought the surface exactly true.

Method of Lining.—The cement men usually followed the finishers, about a half day later. If the earth had dried, it was usually well sprinkled. Wooden strips $1\frac{1}{2}$ inches in width, $\frac{3}{4}$ inch thick, and equal in length to the width of the sloping sides, were placed flatwise on the slopes. They were placed 3 feet apart, and served as guides to a straight edge which assured a uniform thickness of $\frac{3}{4}$ inch mortar.

The mortar was mixed on top of the bank in galvanized iron portable mixing boxes, and spread uniformly between the wooden strips on the slopes. With the straight edge as a guide, all irregularities were removed, and the mortar was finally compacted with the trowel. After the slopes had been lined the bottom lining was put on. A good lining $\frac{3}{4}$ inch in thickness was thus obtained. The bottom width of the canal varies from 5 to 10 feet, and the side slopes are 1 on 1, the depth being $3\frac{1}{2}$ to 4 feet. (Fig. 7.) The lining is extended on each side of the top of the slope to a distance of 5 inches.

The plaster is composed of one part of good Portland cement to four parts of clean sharp sand.

The cost of this class of work, including preparation of the slopes and bottom, and their lining, varies from $3\frac{3}{4}$ to 4 cents per square foot.

The Riverside Water Company has plastered a large portion of its water channels in a very similar manner, the cost being nearly the same.



FIG. 7. Gage Canal; lined with cement mortar.

The Jurupa Canal is lined with cement plaster; the thickness of the lining, however, is only $\frac{1}{4}$ to $\frac{1}{2}$ inch. (Fig. 8.) The earth ditch was



FIG. 8. Jurupa Canal; lined with cement mortar.

not brought to grade as accurately, nor the sides finished as smoothly, as for the Gage Canal Company. The water channel was trimmed approximately with shovels; the sides and bottom were then sprinkled and

the mortar spread with trowels to a uniform thickness as nearly as possible. The cost of this lining was not obtainable, but very similar work used by the Escondido Irrigation District for some of its channels cost from 15 to 20 cents per square yard, or from 1.66 to 2.22 cents per square foot.

A smaller ditch near Hemet, the Little Valley Ditch, 2 feet wide at the bottom, $1\frac{1}{2}$ feet deep, with side slopes of 1 on 1, was lined with cement mortar plaster 1 inch thick at the bottom, and $\frac{1}{2}$ inch thick at the sides. The composition of the mortar for the bottom was one part of California cement to four parts of sand; for the sides it was one part of cement to six parts of sand. The cost of preparing the channel and lining was 18 cents per lineal foot, or 2.88 cents per square foot.

The San Jacinto Water Company, also in Riverside County, has its main canal lined in the same manner as the Gage Canal; the length of the canal is 11 miles, the bottom width is 3 feet, the depth $2\frac{1}{2}$ feet, and the side slopes 1 on 1.

That this type of lining has been successful there is no doubt. Mr. Irving, former engineer for the Gage Canal Company, states in his report that after a test of ten years the lining more than justified their expectations. The cost of repairs after four years' use was very small, less than $\frac{1}{2}$ of 1 per cent of the capital cost in four years.

That there are conditions under which this lining will not be entirely satisfactory has also been demonstrated as follows:

1. For water channels constructed in heavy adobe soil, subject to heaving, it has cracked badly. This is noticeable in parts of the canal of the San Jacinto Water Company.

2. For water channels built in fills, where the ground is subject to settlement.

A better construction in this case is to line the canal with masonry of the type "a" or "b," previously described. The Gage Canal has used masonry very similar to class "a" for the lining of canals when in fill or made ground. This masonry is about 6 inches in thickness and is composed of building stone laid in mortar whose ingredients are one part of Portland cement, three parts of fat lime, and twenty parts of sharp sand. All external surfaces exposed to the action of the water are coated with $\frac{3}{8}$ inch of cement mortar, composed of one part of cement to three parts of sand. The cost of this class of work, which is very similar to class "a," but not so thick, is about $11\frac{1}{2}$ cents per square foot.

The thin plaster lining is subject to rupture where gophers or squirrels burrow behind it, or under it, as the lining has not sufficient strength; also if storm water washes out some of the back filling.

It is probable that this kind of lining would not resist the climate of

a country subject to very cold weather, in which case the stronger lining with proper drainage to prevent the accumulation of water behind the lining would be needed.



FIG. 9. Unlined canal near Lemoore, showing vegetation.

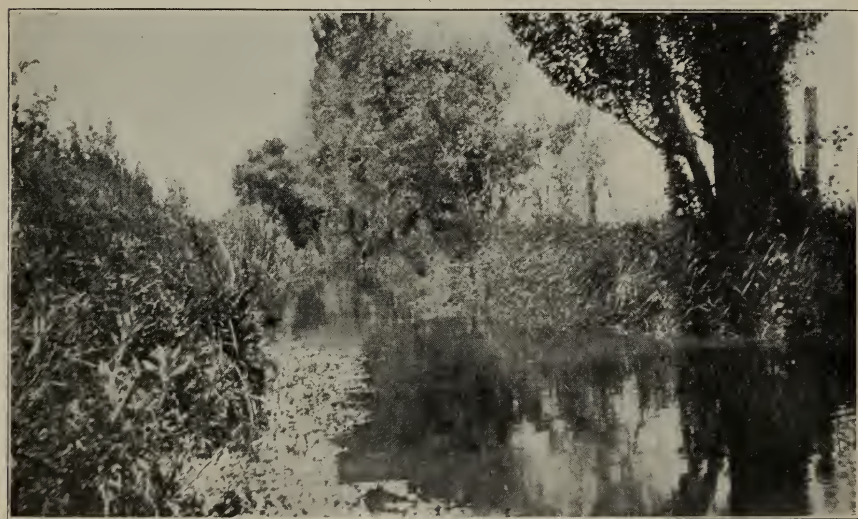


FIG. 10. Unlined canal near Lemoore, showing vegetation.

HEAVY ROAD OIL.

The instances where road oil has been used for canal or reservoir lining are few. The only example of its use for canal lining in California known by the writer, is at Lemoore, in Kings County, on the Madison branch of the Lemoore Canal and Irrigation Company.

In this locality the canals are shallow, the velocity of the water is small, and the growth of weeds and aquatic plants in the canals is abundant. (Figs. 9 and 10.) A large resistance is offered to the flow of water, which means a small carrying capacity, and a large loss due to seepage and evaporation. It is necessary for the irrigator to clean these frequently, sometimes as often as once every two weeks. The labor and cost are considerable.

Mr. McLaughlin, secretary of the Lemoore Irrigation Company, tried as an experiment the use of heavy road oil to prevent the growth of vegetation. The oil was applied in November, 1905, on a length of $1\frac{1}{2}$



FIG. 11. Canal near Lemoore lined with oil.

miles of the main canal. The canal is about 20 feet wide and about 1 foot in depth. (Fig. 11.)

The oil used was crude petroleum from the Sunset District southwest of Bakersfield and contains a large percentage of asphaltum. Its specific gravity is $11\frac{1}{2}$ on the Beaumé scale. This oil when cold will not run freely. It was used hot and sprinkled with an ordinary road sprinkler. The ditch had been previously cleaned of all vegetation and allowed to dry. The road sprinkler was driven first on the bottom of the ditch and then on the banks. The oil was applied at the rate of $11\frac{1}{2}$ gallons per square yard. The oil was then thoroughly harrowed in until it was well mixed with the soil, which was very sandy.

When examined in May, 1906, about seven months after the application of the oil, there was no vegetation in this part of the canal, while other parts of this same canal which had received no oil and had been

cleaned two weeks previously showed a vigorous growth of vegetation. The contrast is very striking and clearly shows the value of oil in preventing the growth of aquatic plants. Not only was this part of the canal free from vegetation, but it was only about one third full, while the canal full of weeds had to be full to carry the same amount of water.

An objection might be made to the use of oil for canal lining because of the fear that the oil might be carried to the fields in sufficient quantity to injure the crops. Mr. McLaughlin states that in this case they had no trouble from this source.

An example of the use of oil for lining reservoirs is found near Bakersfield, where a small reservoir 275 feet long and 75 feet wide is built in almost pure, coarse sand. A centrifugal pump delivered to the reservoir 2,250 gallons of water per minute for twelve hours, and it would leak out as fast as poured in. It was then decided to use road oil to prevent this excessively large seepage. 185 barrels of heavy oil (11 specific gravity Beaumé scale) were poured while hot on the bottom of the reservoir. Since one barrel of oil contains 42 gallons, the rate at which the oil was applied was 3.31 gallons per square yard.

While for the Lemoore Ditch the oil was harrowed into the soil, in this case the oil was poured on the surface and allowed to soak in. This formed a tough asphaltum crust of about 3 or 4 inches in thickness. The seepage was greatly reduced and now the reservoir can be rapidly filled with the same pump.

Another example of the use of oil for lining a reservoir is near Los Angeles—the Ivanhoe Reservoir. (Fig.12.) Here it was found necessary to protect the sloping banks from the erosive action of the waves. On the slopes were spread 3 inches of river sand, fairly clean, and thin oil (16° to 18° Beaumé scale) was sprinkled on the sand and raked in. The amount of oil used was 2.3 gallons per square yard, or 13.35 per cent of the volume of the sand. The slopes of the reservoir were 4 on 1 and 2½ on 1. This lining was being completed when the writer examined it. It has so far answered in a satisfactory manner the purpose for which it was intended. A letter was addressed to Mr. Wm. Mulholland, superintendent of the water department of the city of Los Angeles, inquiring as to its behavior, and his reply, under date of December 20, is as follows:

“The oil lining of the Ivanhoe reservoir has proven a success with the exception of the southern embankment, on which the work was poorly and hastily done. We had a very severe northern gale about a month ago that raised waves at sufficient height to spray clear over the bank, although at that time there was fully 4 feet of clearance. The continued action of this storm for twenty-four hours or more cut many holes in the slope, but an examination of the broken places showed that

the oil had penetrated but an inch or two and was hence insufficient to withstand such violence." Mr. Mulholland further states that with properly executed work the method would prove a complete success.

It will be noted that in this case comparatively light oil was used. It is the writer's belief that heavy road oil would be more efficient in resisting wave action, erosion, or scouring due to water.

From observations of the behavior of oil on roads or streets in resisting the erosive force of running water during heavy rainfall it would seem that an oil lining for canals would allow a very high velocity. Many oiled streets having a steep grade have been constructed with the gutters built of exactly the same materials as the street. These gutters

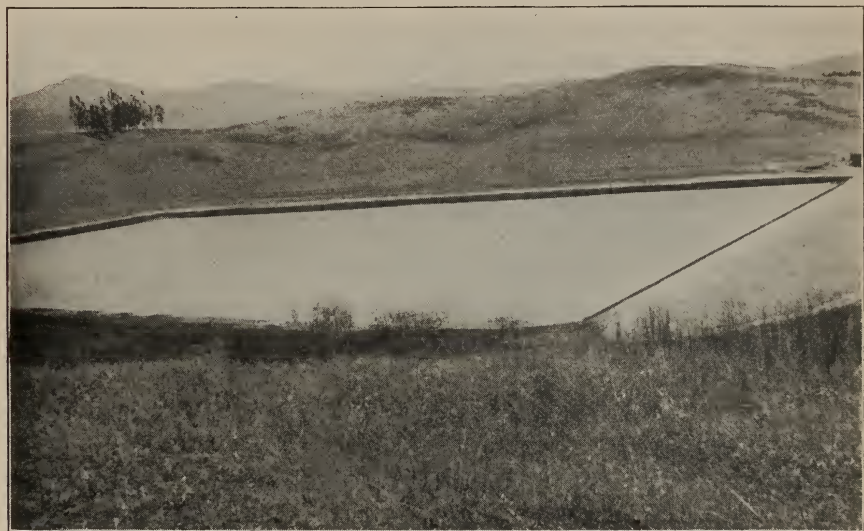


FIG. 12. Ivanhoe Reservoir (near Los Angeles), lined with oil.

during heavy rain storms have had to carry a large volume of water and the velocity was high, still the gutters were not in the least cut up.

A statement from Mr. Theo. White, of Los Angeles, who has made a special study of oiled roads, gives us an idea of what might be expected of oil lining for ditches: "The whole country was flooded and it gave us a good test of our oiled roads. There is a road running into San Bernardino on a grade of about 6 per cent, about 300 or 400 feet from a bench down into a creek bottom. The road had been oiled a second season and there was a good oiled surface. The water rushed down the middle of that road, because the ditches could not carry such a great volume of it, and it did not make a scratch on the road, but a half mile south there was a road of about the same grade which was so badly washed that it could not be used until it was repaired—a road that was not oiled. Between Pomona and Freeman there was a great quantity

of water came from a cañon and struck the oiled road at right angles at one point. It came from the west, and on the east side of that road there was a margin of 6 or 8 inches of the surfacing material that the oil had not touched. The rain passed over the oiled surface, and when it came to that which was not oiled it cut it right out. Upon the same road within the city limits of Pomona the road was surfaced with decomposed granite, packed down hard, and a very nice road during the summer, but it had not been oiled. The same storm cut it all to pieces. On one stretch of a quarter of a mile the road material was fairly washed out into the fields alongside the road."

These examples and observations on the use of oil teach us that it can be used to prevent vegetation in the ditches, to greatly decrease seepage in the sandy soil, and to probably resist erosion due to wave action, or running water.

PUDDLED CLAY LINING.

This method of lining had not been used to any extent in the irrigated districts investigated, and the writer could not learn of any systematic work of the kind.

The cost of this lining would depend on the distance the clay would have to be hauled and the ease with which it can be loaded, and on the way the clay is applied.

Under the best conditions, clay being close at hand, easily loaded and applied cheaply, would be very satisfactory and efficient in stopping seepage. Probably the cheapest method of applying the clay would be to spread it on the bottom and slopes when the clay is soft and moist, or if it can not be obtained in that condition, to spread it after the ditch has been wetted thoroughly by damming up the water and then draining it out; or to spread it dry and then fill the canal and drain the water out. After the clay has been spread as uniformly as practicable, the canal could be fenced in, and cattle or, better, sheep could be driven in the fenced area; they could be fed along the ditch and in this way would tramp the puddle thoroughly.

The cost of such a lining would be mainly the cost of the clay; for a lining 4 to 6 inches thick this cost would probably not exceed 1 to 1¼ cents per square foot.

EXPERIMENTS TO DETERMINE RELATIVE EFFICIENCY OF CANAL LININGS AS REGARDS SEEPAGE.

The purpose of these experiments was to determine the relative efficiency of canal linings, as regards seepage only, and not to compare the resistance of the lining to the cutting or erosive force of running water.

For this purpose twelve ditches closed at both ends were excavated in earth of uniform texture, that they might all be under the same conditions. These ditches were lined with the different materials used in California for the lining of irrigating canals. After the ditches were excavated and lined daily measurements were taken to determine the rate of seepage, and from these the relative efficiency was obtained.

LOCATION AND POSITION OF DITCHES.

The site chosen for the experiments is in Stanislaus County, near Modesto, on the University experimental farm, about $3\frac{3}{4}$ miles east of the town. Lateral No. 1 of the Modesto Irrigation District ran near the south end of the ditches and was the source of water supply for the experiments.

The soil is a fine sandy loam and is very homogeneous to a depth of 2 feet; below this some hardpan was found in the north end of the ditches. This hardpan only occurred in small quantities and was in a soft condition. It could be plowed and removed with scrapers. It is to be regretted that a site with a more sandy soil was not available, as the results might have been more conclusive.

The ditches were parallel and ran north and south, at right angles to Lateral No. 1. (Fig. 13.) The south ends of the ditches were at approximately the same distance from this lateral, so that the seepage from it, if any, would affect each ditch equally.

A wooden flume built with 1-inch by 12-inch redwood lumber, running parallel to the lateral and along the south end of the ditches, carried the water from the lateral to the ditches; a gate in the flume was provided for each ditch.

The ditches were at the same elevation, that the effect of underground water might be equal, and were all $2\frac{1}{2}$ feet deep, with side slopes of $1\frac{1}{2}$ on 1, and a bottom width of 2 feet. A side slope of $1\frac{1}{2}$ on 1 was used because the wet earth in the unlined ditches and the puddle in the puddled ditch would not stand on a steeper slope, and mainly because of the difficulty of oiling the slopes if they had been steeper. The length of the ditches at the top was 50 feet, the ends having also a slope of $1\frac{1}{2}$ on 1; the bottom length was $42\frac{1}{2}$ feet. The top bank width was $4\frac{1}{2}$ feet, making a depth of 14 feet between the ditches, center to center.

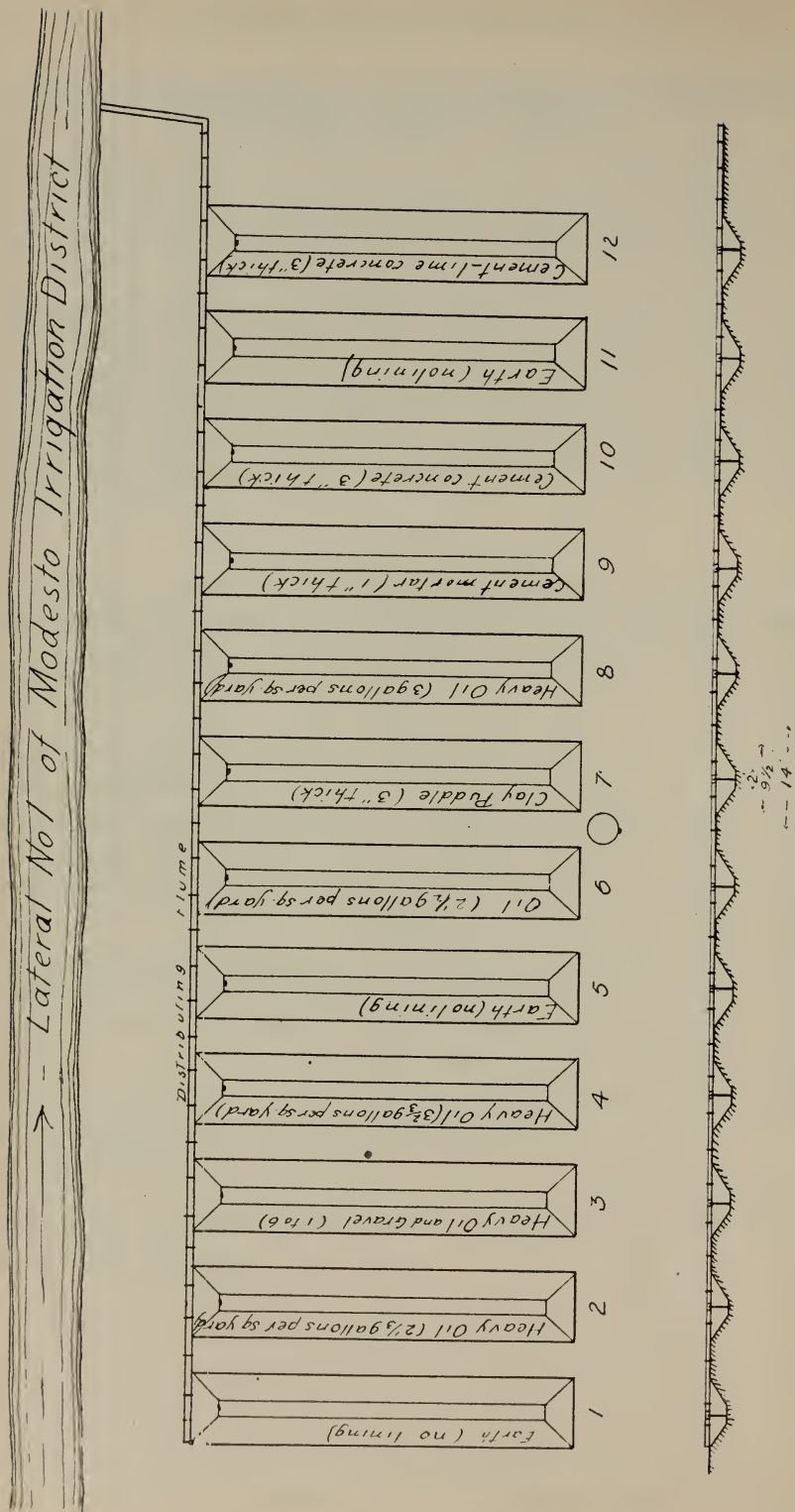


FIG. 13. Position of experimental trenches at Modesto.

METHOD OF CONSTRUCTION.

The site was not exactly level. It was thought best to make it so, that the ditches might be more nearly under the same conditions. The land was irrigated and plowed and the earth from the higher part of the plot was removed with Fresno scrapers and carried off the site. The ditches were all in cut. After the surface was made level, the grade stakes were located and the excavation of the ditches begun. Each ditch was plowed deeply and the earth removed at first with Fresno scrapers, but as the bottom was reached the smaller scrapers (scoop scrapers) were used. In this manner the ditches were excavated roughly to the required cross-section. The total volume of excavation was approximately 500 cubic yards and the total cost was \$95, or at the rate of 19 cents per cubic yard.

LININGS TO BE USED.

The linings which it was thought advisable to try in the experiment were:

1. Cement concrete similar to that used by the Santa Ana Water Company and the Anaheim Water Company.

2. Cement mortar and cement plaster 1 inch thick as used around Riverside by the water companies (Jurupa, Gage, and Riverside) and in several other localities in southern California.

3. Cement lime concrete. It was thought that the addition of some lime to take the place of part of the cement in the concrete similar to No. 1 would perhaps make the concrete more water tight and also slightly cheaper in some localities.

4. Puddle.

5. Road oil in various proportions per square yard of surface and also as a mixture of oil and gravel. The extensive use of oil and its success in road oiling when properly used, especially in southern California, where in many cases the oiled streets are almost as good and even in a few cases better than asphaltum, made it advisable to try oil in several ways.

For a good oiled road, a good foundation and a well-rolled wearing surface are necessary. The quantity of heavy road oil necessary should not exceed $1\frac{1}{2}$ gallons to the square yard.

For canal lining, the conditions are somewhat different from those found in road construction. A good foundation is not necessary. It is impracticable to roll the slopes and beds, and even if practicable, the cost might not justify it. The lack of rolling must be made up by using more oil, and in these experiments a greater quantity of oil was used per square yard than is ordinarily used on roads. Mixtures of oil and

gravel were also used in the experiments, and while they were costly, they were at the same time unsatisfactory, proving very poor linings for stopping seepage, as will be shown later.

The order in which the ditches were planned at first is as follows, the ditches being numbered from east to west:

No. 1. Lined with a mixture of heavy road oil and gravel in the

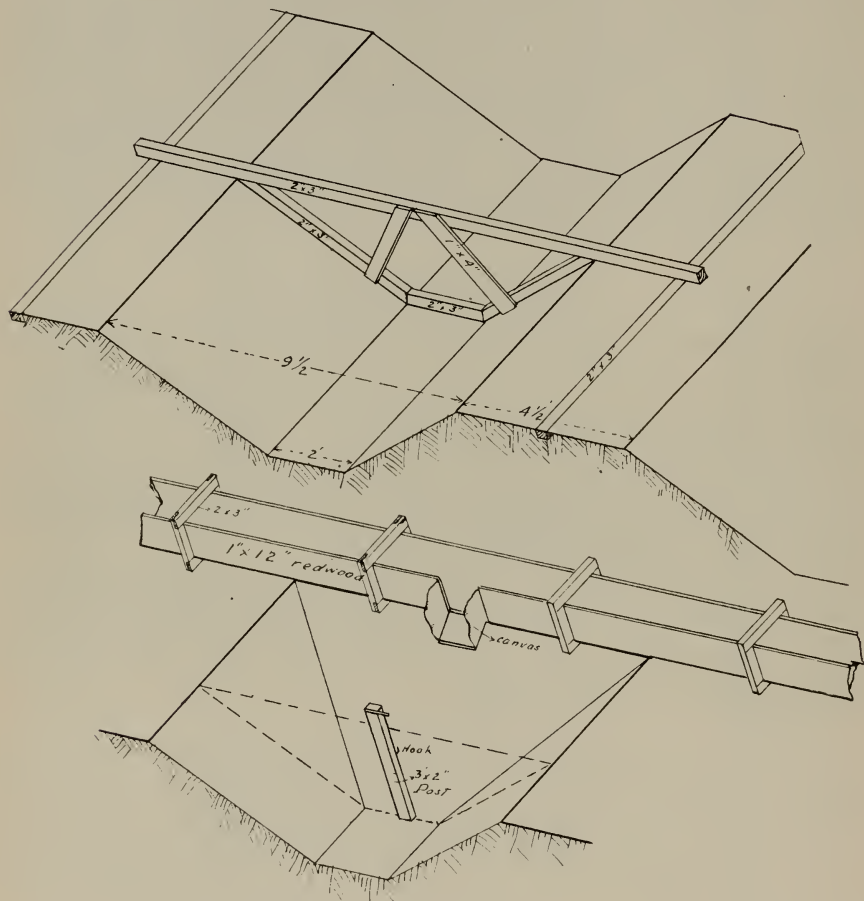


FIG. 14a. Method of using templet.

FIG. 14b. Distributing flume—Gate—Measuring post.

proportion of one part of oil to eight parts of gravel. The lining was $3\frac{1}{2}$ inches thick.

No. 2. Earth (no lining).

No. 3. Lined with a mixture of heavy road oil and gravel in the proportion of one part of oil to six parts of gravel. The lining was $2\frac{1}{2}$ inches thick.

No. 4. Heavy road oil sprinkled, using $3\frac{2}{3}$ gallons per square yard.

No. 5. Earth (no lining).

- No. 6. Thin oil sprinkled, using $2\frac{1}{2}$ gallons per square yard.
- No. 7. Clay puddle, $3\frac{1}{2}$ inches thick.
- No. 8. Earth (no lining).
- No. 9. Cement mortar, 1 inch thick.
- No. 10. Cement concrete, $2\frac{1}{2}$ inches thick.
- No. 11. Earth (no lining).
- No. 12. Cement lime concrete, $2\frac{1}{2}$ inches thick.

It will be noticed that arranging the ditches as above, there are eight ditches lined and four earth ditches with no lining. Each earth ditch has an adjacent lined ditch on each side, so that in case the seepage from the four earth ditches was unequal, the seepage in the lined ditches



FIG. 15. Method of using templet to finish trenches.

could be compared with the seepage from the adjacent (or nearest) earth ditch. The lined ditches would also be affected more nearly equally by the seepage from the earth ditch.

METHOD OF FINISHING DITCHES.

After the excavation with teams the ditches were finished by hand in the following manner (Fig 14): Pieces of timber, 2 inches by 3 inches, were placed at the center of the banks between ditches, and extending parallel to them from one end of the ditch to the other; these pieces of timber were placed in the banks and made level. The top of these timbers was at the same level as the banks. Frames or templets were built, as illustrated, of the same size as the finished ditch, ready for the lining. Four of these frames were used, the same one being used for the four earth ditches and for the ditches where the oil was sprinkled

on the slopes and bottom. A second form was used for the cement mortar lined ditch; this form was larger than the previous one, allowing 1 inch for the lining. The third form was made large enough so that the ditch finished with this form, after being lined with a $2\frac{1}{2}$ -inch lining, would be of the same cross-section as the earth ditch. The fourth form was used where the ditch was to be lined with a $3\frac{1}{2}$ -inch lining.

These frames were used in the following manner (Fig. 15): Beginning at one end the frame was placed in the ditch and the side slopes and bed were cut down until the top piece of the frame would rest on the two pieces of timber on the banks. The frame was then moved forward on these guides and the cross-section was cut down with spades to the proper size. The slopes were finished first and the earth cut from the slopes was removed with a scoop scraper. The cost of finishing was about 1 cent per square foot.

METHOD OF LINING.

No. 1. The oil was heated to a temperature of about 180° Fahr., at which temperature it would flow easily. This heated oil was mixed with the gravel in the proportion of one part of oil to eight parts of gravel by volume. The mixing was done with rakes and the mixture was very uniform. The sides were lined first.

Pieces of timber $3\frac{1}{2}$ inches thick were placed on the slopes at right angles to the axis of the ditch, about every 10 feet. The oil-gravel mixture was carried in wheelbarrows and dumped on the slopes between these timbers. A straight edge about 12 feet long, extending from one timber to the other and worked up and down the slope, regulated the thickness of the lining to $3\frac{1}{2}$ inches. The mixture was tamped while being placed in position.

No. 3. This ditch was lined in exactly the same manner. The mixture used contained one part of heavy Bakersfield oil to six parts of gravel. The thickness of the lining was only $2\frac{1}{2}$ inches; the slope timbers being therefore $2\frac{1}{2}$ inches thick instead of $3\frac{1}{2}$ inches thick, as for No. 1.

No. 4. This ditch was lined with the same heavy oil. The oil was heated to a temperature of 180° Fahr., and was sprinkled or poured on the slopes with a 3-gallon watering pot, with the rose sprinkler flattened so as to throw a flat stream or sheet of oil on the side of the ditch. The oil was applied mostly on the top of the slope, and as it ran down the slope it was gradually absorbed by the ground—some of it reaching the bottom. An excess of oil accumulating at the bottom was dragged up the slopes by using a stick about 8 feet in length to which a 2-foot piece of timber was nailed, at right angles, at one end, and to this piece was nailed a couple of sacks to be used as a mop. If the oil

is not applied in large quantities at once, but instead several successive light applications are made, it will not be found necessary to use this mop.

The oil was not raked in; the object sought for was to have the oil form a thoroughly saturated crust; while if it was raked or plowed in, the oil may have been disseminated through too thick a layer to form a water-tight crust.

No. 6. The sixth ditch was sprinkled with lighter oil in exactly the same manner as the fourth ditch, using $2\frac{1}{2}$ gallons per square yard.

No. 7. The seventh ditch was lined with clay puddle. The clay was difficult to obtain, having to be hauled about three miles, which made it very costly. The clay contained fine silt and sand. It was sprinkled with water, and when soft was hauled in wheelbarrows and applied in the same manner as the oil-gravel mixture. The thickness of the lining was $3\frac{1}{2}$ inches.

No. 9. The ninth ditch was lined with cement mortar, composed of one part of cement to five parts of gravel. The lining being 1 inch thick, the scantlings or guides placed on the slopes were only 1 inch thick.

No. 10. This ditch was lined with cement concrete $2\frac{1}{2}$ inches thick, composed of one part of cement to seven parts of gravel and crushed rock, in equal quantities.

No. 12. The twelfth ditch was lined with cement lime concrete $2\frac{1}{2}$ inches thick, composed of $\frac{2}{3}$ part of cement, $\frac{1}{3}$ part of lime, and seven parts of gravel and crushed rock in equal quantities.

Before lining with cement mortar, cement concrete, and cement lime concrete, the slopes and bed of the ditches were well wetted by sprinkling. These three linings were also kept wet for several days after the construction.

The oil ditches had been finished about ten days before the water was turned into them. This was necessary for the oil to soak in well and also for the lighter volatile parts of the oil to evaporate. The water was first turned in on July 23, 1906, and observations were then started.

METHOD OF OBSERVATION.

The ditches were filled each morning to a depth of 2 feet (approximately), the measurements being taken as soon as filled. Measurements were again taken late in the afternoon and also the next morning before refilling the ditches. The instrument used to take the measurements consisted of a wooden post, 2 inches by 3 inches, which was driven firmly in each ditch at the south end. The top of the post was about 3 feet from the bottom of the ditch. A right-angle screw hook, with the shorter arm filed to a point, was screwed into the post. The depth from

the bottom of the ditch to the end of the hook was 2 feet. This served as a guide in filling the ditch, each ditch being filled as nearly as possible up to this hook. For an exact measurement a piece of steel about 5 inches long, $\frac{1}{8}$ inch thick, and $\frac{3}{4}$ inch wide, was screwed at the top of the post and at right angles to it. This piece of steel projected about 2 inches beyond the post and its upper edge was beveled. This edge was the index from which the measurements were taken. (Fig. 14*b*.) The measurements being taken with a plumb-bob attached to a steel tape, the steel tape was placed next to the index and the plumb-bob lowered until the point of the bob touched the water. Accurate measurements could thus be taken to $\frac{1}{2}$ of a hundredth of a foot (.005 foot).

Evaporation.—The evaporation was determined by means of a galvanized iron tank placed at the north end of the ditches, between ditches No. 6 and No. 7. Measurements were taken in the morning and in the afternoon in the same manner as for the ditches.

From the observations taken beginning with the 23d and extending until the 28th of July, it was found that the lining of ditches No. 1 and No. 3 was entirely unsatisfactory, as the seepage in them was larger than in the earth ditches with no lining. It is probable that the water percolated through this lining and was carried away through gopher and squirrel holes under the lining. In the earth ditches gopher and squirrel holes were found, but could be stopped; but this oil and gravel mixture had sufficient strength not to break through where the holes were, and they could not be discovered.

From the observations during these few days it was found that the seepage in all four earth ditches was almost identical, so it was decided to sprinkle oil on two of these earth ditches, using in both cases less oil than was used on ditch No. 4.

The gravel-oil mixture was removed from No. 1 and this ditch was used as an earth ditch. Ditch No. 3 was not changed; measurements on this ditch were continued, but it did not improve.

The ditches after July 28th were allowed to dry and after the changes were made were in the following order:

New Order of Ditches.

No. 1. Earth (no lining).

No. 2. Heavy oil sprinkled, $2\frac{1}{3}$ gallons per square yard.

No. 3. Heavy oil and gravel, one part of oil to six parts of gravel ($2\frac{1}{2}$ inches thick).

No. 4. Heavy oil sprinkled, $3\frac{2}{3}$ gallons per square yard.

No. 5. Earth (no lining).

No. 6. Thin oil, $2\frac{1}{2}$ gallons per square yard.

No. 7. Puddled clay, $3\frac{1}{2}$ inches thick.

- No. 8. Heavy oil sprinkled, $3\frac{1}{3}$ gallons per square yard.
- No. 9. Cement mortar, 1 inch thick.
- No. 10. Cement concrete, $2\frac{1}{2}$ inches thick.
- No. 11. Earth (no lining).
- No. 12. Cement lime concrete, $2\frac{1}{2}$ inches thick.

The table accompanying this report (see page 414) refers to the ditches after they had been changed.

The water was again turned into the ditches on August 6th, but because of a serious break in the main canal of the irrigation system, the water could not be obtained again until August 28th. Observations were again begun and were taken until September 10th, a period of fourteen days.

For the first four days the results were not very uniform; probably because some of the ditches had held water much better than the others during the interval when no water was available for filling them. The rates of percolation per hour given in the table are the rates of percolation for the last ten days. This rate of percolation is computed from the readings taken each day. The seepage and evaporation for each ditch, from the time the ditch is filled to the time when the level of the water is measured next morning just before filling, give the total seepage and evaporation for that time. Subtracting from this the loss in level due to evaporation gives the loss due to seepage. This quantity divided by the number of hours in which this loss occurred gives the rate of percolation or seepage in feet per hour.

Consulting the table, it will be noticed that the rates of percolation for the three earth ditches were very nearly equal. However, in comparing the seepage from the lined ditches with the seepage from the earth ditches, the relation is obtained by making the comparison with the nearest earth ditch.

The efficiency of a ditch is the ratio between the rate of percolation for the earth ditch and the rate of percolation for the adjacent lined ditch; or, efficiency = rate of percolation for earth ditch over the rate of percolation for lined ditch. The larger this ratio the more efficient or water-tight is the lining.

From the mean sinkage or mean percolation of the several ditches is computed the percentage of saving due to the lining in each case. This saving indicates the probable percentage of water saved from the loss which would take place if the ditch was not lined. The experimental cost per square foot of the lining is the actual cost at which the work was done. It does not include the cost of finishing and preparing the ditch for the lining. This cost was about 1 cent per square foot.

The actual cost per square foot for work on a larger scale would naturally be somewhat smaller. The cost given in the table is estimated

1. Table showing Rate of Percolation.

No.	Kind of lining.	Rate of percolation, in inches, per hour for ten consecutive days.										Average	Efficiency ratios
		1st	2d	3d	4th	5th	6th	7th	8th	9th	10th		
1	Earth, with no lining	.029	.032	.031	.034	.032	.033	.033	.031	.032	.032	.0329	.0329 = 1.00
2	Heavy oil, $2\frac{1}{2}$ gallons per square yard	.026	.026	.025	.023	.025	.022	.023	.024	.032	.032	.0239	.0329 = 1.37
3	Heavy oil and gravel												
4	Heavy oil, $3\frac{3}{4}$ gallons per square yard	.022	.020	.019	.018	.016	.016	.016	.017	.016	.016	.0176	.0355 = 2.02
5	Earth, with no lining	.040	.036	.034	.034	.034	.035	.036	.033	.037	.036	.0355	.0355 = 1.00
6	Thin oil	.035	.034	.032	.031	.032	.032	.033	.030	.034	.032	.0329	.0355 = 1.08
7	Clay puddle	.021	.019	.018	.018	.018	.019	.017	.018	.019	.018	.0185	.0185 = 1.78
8	Heavy oil, 3 gallons per square yard	.024	.023	.024	.021	.024	.021	.021	.020	.022	.020	.0220	.0355 = 1.50
9	Cement mortar, 1 inch thick	.014	.012	.013	.011	.012	.013	.011	.012	.011	.012	.0121	.0330 = 2.73
10	Cement concrete, 3 inches thick	.006	.005	.004	.004	.005	.004	.006	.004	.004	.004	.0046	.0330 = 7.17
11	Earth, with no lining	.035	.036	.035	.034	.032	.036	.032	.032	.031	.030	.0330	.0330 = 1.00
12	Cement lime concrete, 3 inches thick	.010	.012	.009	.008	.011	.010	.009	.011	.012	.012	.0114	.0330 = 2.90

from similar work in existence and agrees with the cost in the examples mentioned in the first part of this paper. For oil lining the cost would depend largely on the price of oil. The price assumed in preparing the table was 2 cents a gallon for the oil and 1 cent a gallon to apply it. For cement concrete or cement mortar it is customary to prepare the ditch and finish it carefully. The bottom and side slopes are made even and regular. The cost of finishing on a large scale for first-class work would probably be less than the actual cost on the experimental ditches and would probably not exceed $\frac{3}{4}$ of a cent per square foot.

For oil and puddle linings, it would not be necessary to finish the ditch so carefully. The removal of weeds may be the only preparation necessary.

MATERIALS AND COST.

Cement.—California Portland cement (Standard Brand), at \$3.00 a barrel in Modesto.

Lime.—Roach Harbor lime, at \$2.50 a barrel in Modesto.

Broken Stone.—Obtained from Folsom, Cal., at \$3.00 a cubic yard in Modesto.

Gravel.—Clean river sand, varying from 1-inch pebbles to coarse sand, obtained from Dry Creek, about 3 miles from the site of the experiments, at 10 cents a cubic yard. The charge for hauling to the site was \$1.50 per cubic yard.

Puddle.—Difficult to obtain. The only clay available was about 3 miles from the site, and it had to be dug with picks. The charge for loading and hauling was about \$1.50 per cubic yard.

Heavy Oil.—Natural crude mineral oil ($10\frac{1}{2}$ to $11\frac{1}{2}$ degrees Beaumé), from the Sunset District near Bakersfield, Cal., containing not less than 60 to 80 per cent by weight of "D" grade asphalt. The percentage of asphalt is not always dependent on the specific gravity. With two oils of the same gravity, one may contain 80 per cent of asphalt and the other none. The oil was obtained at 85 cents a barrel (42 gallons), delivered on the site.

Light Oil.—Natural mineral oil (16 degrees gravity) containing about 35 to 40 per cent of "D" grade asphaltum. The price was 85 cents a barrel.

Cost of Labor.—All labor cost \$2.50 for an eight-hour day; one foreman at \$5.00 for an eight-hour day, and a teamster with team \$4.50 per day.

RESULTS OF OBSERVATIONS AND EXPERIMENTS.

A study of the table shows that cement concrete 3 inches thick stopped 86.4 per cent of the seepage which occurred in an earth ditch excavated in the same material. This percentage would probably have been larger had the earth been more porous; for this would make the loss in earth ditches greater, while the loss from the cement concrete ditch would probably not have been increased. This is true also, but probably not to the same extent, for the other lined ditches. However, it is quite safe to believe that in more porous or open soil the percentage saved by lining would be greater than shown in the table.

2. Table showing Results of Experiments.

Description of lining.	Average mean sinkage per hr. in feet exclud- ing evapora- tion	Efficiency ratios	Percent saving	Experimental cost of lining per sq. ft.	Actual cost of lining per sq. ft *
Cement concrete, 3 inches thick	.0046	7.17	86.6	Cents. 83	Cents. 7.5
Cement lime concrete, 3 inches thick	.0114	2.90	65.5	8.3	7.5
Cement mortar	.0121	2.73	63.3	3.88	3.25-3.50
Heavy oil, $3\frac{3}{8}$ gallons per square yard	.0176	2.02	50.4	1.20	1.20
Clay puddle, $3\frac{1}{2}$ inches thick	.0185	1.78	47.8	3.90	1.20
Heavy oil, 3 gallons per square yard	.0220	1.50	38.0	1.00	1.00
Heavy oil, $2\frac{1}{3}$ gallons per square yard	.0239	1.37	27.3	.77	.77
Thin oil, $2\frac{1}{2}$ gallons per square yard	.0329	1.08	7.3	1.00	.80
Earth (no lining)	$\left\{ \begin{array}{l} .0329 \\ .0355 \\ .0330 \end{array} \right\}$	1.00	0.00	-----	-----

* Excluding the preparation of the ditch. (Last two columns.)

While there is no doubt but that cement concrete is the most efficient as regards seepage, it is also the most expensive, being more than six times the cost of the heavy oil lining ($3\frac{3}{8}$ gallons per square yard), which saves 50.4 per cent of the water which would seep were the ditch not lined. This saving with the concrete ditch is 86.6 per cent, or $1\frac{3}{4}$ times as large. Where water is very valuable there is no doubt but that the concrete ditch is more permanent and economical. But where the water is not so scarce and a little waste will do no damage, the expense of lining the ditch with oil may be justified, while a more expensive lining would be impracticable.

The question will come up: "Is it economical to use oil on a ditch to save 50 per cent or less of the water which is being lost in ditches not lined?" Perhaps there is a great deal of water, and in many irrigated districts the waste of water seeping from the canals and laterals while large is small compared with the larger waste due to over-irrigating the fields and to poor methods of irrigation. These conditions will no doubt better themselves as California becomes more settled and the water is more economically used and more valuable. But even under the present conditions the advantage of lining a canal is not alone the decrease in seepage; other factors should be considered, as mentioned in the first part of this paper. (1st) The prevention of growth of vegetation is an important item and is quite an expense, when in most cases the ditch or lateral must be cleaned out several times during an irrigation season. (2d) The resistance to scouring, on which depends the velocity which the water can be given. (3d) The prevention of squirrels and gophers from burrowing into the banks and bottom of ditches.

That oil will prevent vegetation and the burrowing of animals on the banks and bottom of the ditch is clearly shown by the example near Lemoore, previously mentioned.

That oil will prevent scouring to a great extent and will allow a much higher velocity of flow of water than the earth ditch may be expected, when we consider its resistance to wave action at the Ivanhoe Reservoir, and the resistance of oiled roads to cutting under the action of running water. This toughness of oil lining was also noticed in filling the experimental ditch each morning. When the water carried by the wooden flume discharged into each ditch through the gate it had a fall of at least one foot. It was difficult to prevent the sloping ends of the earth and puddle ditches from being badly cut up by the erosive force of the falling water. These ends had to be well protected with heavy canvas, and even the erosion could not be altogether prevented. The ditches lined with oil resisted the erosion and showed no cutting, although they were not protected with canvas.

A letter from the superintendent of the Modesto Irrigation District, dated January 21, 1907, states that the ditches were examined by him after the recent heavy rainfalls. The banks of the earth ditches were badly washed where the water ran in; the clay puddle was slightly so, but the oiled ditches showed absolutely no sign of wash. The oil linings are all hard and firm and scratch almost like concrete.

This resistance to erosion will permit in a saving of cross-sectional area due to the possibility of giving the water an increased velocity. The higher velocity will prevent the deposition of silt to a great extent and there will be a consequent decrease in the cost of operation and maintenance.

The puddle lining in the experiment showed a saving in seepage nearly equal to the heavy oil lining when $3\frac{2}{3}$ gallons of oil per square yard was used, and a greater saving than the other oil linings. This puddle lining, whose thickness was $3\frac{1}{2}$ inches, would, no doubt, if made thicker, be more efficient than any of the oil linings as regards seepage; but clay puddle when wet becomes very soft and will not resist the erosive force of the flowing water unless the velocity is very small. It will not prevent the growth of weeds. For these reasons it is probably not as efficient for canal linings as oil. But where clay is plentiful it would be preferable for reservoir lining. The slopes should, however, be protected against the erosive action of the waves by the use of cobblestones or other protection.

The use of oil in lighter quantities, while not very efficient in preventing seepage, will no doubt prevent the growth of vegetation, as illustrated by the example of the ditch near Lemoore. In this case only $11\frac{1}{2}$ gallons per square yard was used and this quantity has been sufficient to prevent vegetation.

Cement mortar plaster, so extensively used in southern California, showed a saving in seepage water of 63 per cent. Better results were expected, and it is probably safe to expect a greater saving where good work is done, especially where the work is constructed in cold weather. This lining had to be applied when the temperature in the field was probably 110° or over. The cement mortar was mixed in small quantity and quickly applied. As soon as the setting had started the lining was sprinkled and covered with wet canvas, but even with these precautions better work could be done in cooler weather.

This plaster, while very efficient and economical on small ditches, would not be of sufficient thickness and strength to be used on the larger canals and laterals of larger irrigation systems, where a thickness of from 2 to 4 inches would no doubt be successful.